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(Plenum Publishing Corporation, 1981)

METHODS: PAST APPROACHES, CURRENT TRENDS AND FUTURE REQUIREMENTS

Donald A. Topmiller

INTRODUCTION AND HISTORICAL ANTECEDENTS

The field of Human Factors Engineering in the United States evolved out of demands from the increasing complexity of military weapon systems in World War II. The early workers in the field such as Paul Fitts in the Air Force, Adelbert Ford in the Navy and a little later John Weisz in the Army, were all trained as experimental psychologists, hence the methods applied during these years were transitioned almost directly out of empirical applied psychology. This was formally recognized in 1949 with one of the first published texts in the field (Chapanis et al., 1949).

During the early and mid 1950s, the application of the tools of the experimental psychologist to man-machine design problems continued to flourish. We also saw, during this period, an attempt to extract from the existing experimental literature, human performance limits, given certain man-machine interface characteristics, environmental conditions, and task environments. An excellent early effort to do this was reflected in the publishing of the "Tufts Handbook" or the Handbook of Human Engineering Data in 1951. This was the authoritive reference document for Human Engineering Data for over ten years. In the early sixties the three military services convened the Joint Army-Navy-Air Force Steering Committee to publish the Human Engineering Guide to Equipment Design. The first edition was published in 1963 and the revised second edition in 1972. The respective services also published numerous engineering handbooks of human engineering design principles and criteria.

The underlying assumption during the "Handbook Era" was that design engineers and system engineers would apply the appropriate human

engineering data to manned systems design problems. Frequently, this was found not to be the case for several reasons. First, many design engineers were not aware of the existence of the handbook data, or if they were, there was very little incentive to use the data in their design trade-off analyses. (This was often the fault of the government program management since no requirement for the application of human factors was included in the contract.) Secondly, if the need was recognized, the design engineer could not apply the data since the problem or intended operational use of the system did not correspond to the conditions under which the data were experimentally derived. Finally, an integrating structure for the data base which was systems and problem specific did not exist. It was frequently found that in order to solve a specific design problem, a physical simulation, or at least a functional mock-up, of the manned system design was required. Depending on the significance of the design issue and the expense involved, the solution may or may not have been assured by physical simulators.

This situation was probably characteristic of the human factors state-of-the-art in the mid 1960s. The experimentalist, qua human engineer, found that experimental methodology used in problem specific cases was often extremely expensive and may or may not address the operational or system variables critical to the design issue. We also saw during the same period an explosive growth in digital computer technology. This technological development was exploited by the operations research community and led to the rapid computerization of large multivariate systems simulations as well as the coincident development of computer simulation languages. The first psychologist to recognize, and eventually implement, the power of the computer simulation to man-machine system design problems was Arthur Siegel from Applied Psychological Services, who along with Jay Wolf, a mathematician, under the Office of Naval Research contract developed the first 2-operator model and in 1969 published the first book in man-machine simulation models (Siegel and Wolf, 1969). Certainly this development contributed a quantum jump in human factors methodology and eventually led to several man-machine systems design and analysis techniques such as CAFES (Computer Aided Function-Allocation Evaluation System) in the Navy, with its associated submodels, and SAINT (Systems Analysis Integrated Network of Tasks) in the Air Force. Human factors engineering recognized that in order to get man-machine design principles integrated into system design and development programs, it would have to borrow heavily from the systems simulation and operations research communities.

In fact, in the mid-sixties our Laboratory sponsored a contractual survey with Air Research Incorporated to evaluate the extent to which human factors (man-machine interface) parameters had been incorporated into military Operations Research (OR) studies (Schwartz et al., 1967). A total of 250 studies were reviewed covering a period from World War II until 1965. Detailed analysis was made on 20 of

the most representative studies to evaluate the extent to which human factors variables were incorporated into the study, and the degree to which the model was sensitive to variations in the human factor parameter values. The detail review included:
- Description of the system modeled.
- Discussion of the problem treated and objectives of the analysis.
- Identification of the OR techniques used. (Hopefully a "classical" OR model.)
- Identification of the human factors parameters relevant to the model of the systems.
- Discussion of the role and treatment of human factors parameters found in the model.
- Discussion of the sensitivity of the model to changes in values of the human factors parameters.

From the analysis ensuing from the above objectives, the study lists the following conclusions:
- There is a strong tendency for OR investigators to concentrate too heavily on the model rather than the natural system problems.
- The relative sensitivity of various OR techniques to variations in human factor variables were difficult to assess for the models surveyed because:
  a. The majority of OR analyses do not analytically treat human performance parameters (affecting system performance), since they seem imbedded in the terms of various OR models, but precise relations among the parameters and OR model terms are not demonstrated.
  b. In the studies which treat human performance variables, the parameters considered and systems, or contexts, modeled are too diverse to permit direct and quantitative comparison.
  c. The lack of standard measure of human performance in systems serves to increase the complexity of the problem.

In retrospect this is a lesson in irony since Siegel and Wolf at that time had not received wide publicity in their model development efforts, but must have recognized these deficiencies which stimulated their use of monte-carle techniques for developing the original 2-man model

At the turn of the decade into the seventies, we saw these major trends in man-machine design methods and techniques development. First, with the stage set by the technological breakthrough in computer power many human factors groups in industry and government either developed their own computer-controlled engineering design simulation capability for performing single-operator and multi-operator (crew) real-time mission-based simulation or they piggy-backed studies on simulation facilities developed and controlled by hardware engineering groups. Many of these facilities were used to investigate advanced cockpit designs, advanced control-display concepts and/or measurement of pilot/crew workload. It was fortuitous that this high-

technology capability in man-machine design physical engineering simulation filled a unique requirement, since during the seventies, the national defense policy was one of enhancing existing weapon system capability by hardware/software modification and upgrade rather than investing in new weapons per se. This was particularly true of the decisions not to produce the B-1 and instead upgrade the avionics (electronic warfare and navigation) capability of the 20 year old B-52. Our Laboratory developed the SACDEF (Strategic Air Command Design Evaluation Facility) to evaluate the operator/crew performance aspects of the "improved" avionics systems. Our Laboratory also developed a computer-based multi-operator command/control simulation facility on which many simulation of BUIC (Back-Up Interceptor Control), AWACS (Advanced Warning And Control System) and RPV (Remotely Piloted Vehicle) surveillance and weapons direction mission were conducted. This program is summarized in a chapter by the author in Tsokos and Thrall (1979). In fact, in our BUIC simulations we attempted for the first time to integrate computer-simulation with multi-operator/multi-task real-time physical simulation. Where we had the capability to conduct the physical simulation of the operational BUIC "active tracking" tasks, we did so. Those operational tasks which could not be physically simulated, by virtue of computer and display limitations, we computer-simulated using a Siegel-Wolf model. This enables us to combine the respective powers and advantages of both simulation disciplines into one "hybrid" technique. It was indeed interesting and gratifying to find that the independent variables we were manipulating in the experimental simulation such as radar track trail length and penetrator velocity had significant effects on task performance measures such as "tracker initiation time" and were not washed-out by the potential propagation of sampling error in the monte-carlo process in the Siegel-Wolf model. Unfortunately, for a variety of reasons, we have not followed through on this "hybrid" technique to develop it to its highest potential as a manned systems simulation and design tool.

In the thirty some odd years covered in this very brief and sketchy treatment of the historical antecedents to the methods used in manned systems design, we have seen our field evolve out of the early work in applied experimental psychology through the design handbook era and becoming more interdisciplinary with strong technological influences stemming from the fields of computer and information science with overtones of operations research and systems simulation and modeling.

CURRENT TRENDS

The US Air Force Systems Command has for the past year and a half conducted a very comprehensive study of the Human Factors Engineering (HFE) field and its technology base development, application of principles, tools, methods, and design criteria throughout the re-

search and development phases of AF Weapons Systems Acquisition. It also included extensive examination of HFE problems associated with acquiring and developing professionals in the Air Force, both civilian and military to meet the demands of advanced weapon system development, acquisition and operation.

The study was conducted primarily by a select group of senior nationally and internationally renowned human factors engineers who performed under contract to the Air Force. Certain senior military and civilian HFE worked with the contract professionals to provide needed governmental information.

Robert C. Williges and the present author worked collaboratively on one of the four task committees to perform the "Technology Assessment" (Williges and Topmiller, in press) task the results of which were relied on heavily to develop this section on Current Trends and the final section on Future Requirements.

For purposes of the "Technology Assessment" task, technology includes information, methods, and concepts/devices created for useful Human Factors Engineering (HFE) purposes. These technologies were classified into the following categories:

1.0. Reference Data Sources - These are catalogs of already collected data which maybe measures of human properties, limits, tolerances task performance capability, interface design principles, design criteria and operator-machine centered equipment, subsystem or system data.

2.0. Experimental Design Methods - are means by which data are collected to enhance the data bases, to draw inferences and to solve problems.

3.0. Human-Machine Integration Performance Metrics - are measurements used in data collection/problem solutions.

4.0. Models - are means of organizing information to represent the functioning of objects/processes being modeled by imposing formalistic rules and relationships.

5.0. Engineering Design Simulation - is concerned with the use of simulation as a design tool and is not to be confused with the production or use of training simulation.

6.0. Procedures - are rationally organized steps to aid in the production of a design (at any stage), evaluation of a design, or in extraction, extension or analysis of a design.

To idenfity specific HFE technologies falling under the six broad categories a total of one hundred and thirty-six (136) subcategories of technologies were used for collecting the data base from which the study developed its findings and conclusions. Table 1 lists the aggregate of technologies examined.

Table I. Listing of Current HFE Technologies

1.0. Reference Data Sources
- Scientific & Engineering Data Sources
- Professional Journal Literature
- Handbooks, Guides, Specs
  - Design Handbook 1-3
  - NASA Bioastronautics Data Book
  - Design Handbook for Image Interpretation Equipment
  - Human Engineering Guide to Equipment Design
  - MIL Spec 1472
- Data Bases
  - Anthropometric Source Book & Data Bank (static & dynamic)
  - Old Systems Record Review
  - SHERB (Sandia Human Error Rate Bank)
  - HFTEMAN (Human Factors Test & Evaluation Manual)

2.0. Experimental Design Methods
- 2.1. Statistical Procedures
  - Univariate Methods
    - Correlations
    - Simple Regression
    - Parametric Inferences
    - Nonparametric Inferences
  - Multivariate Methods
    - Multiple Regression
    - Polynomial Regression
    - Canonical Analysis
    - Principal Components
    - Factor Analysis
    - MANOVA (Multivariate ANalysis Of VAriance)
    - Discriminate Analysis
  - Pretesting Methods
  - ANOVA Designs (ANalysis Of VAriance)
  - DATA Reduction Designs
    - Blocking Designs
    - Hierarchical Designs
    - Fractional-factorial Designs
    - Central-composite Designs
- 2.2. Tailored Methods
  - Confusion Matrices
  - Quasi-experimental Designs
  - Response Surface Methodology
  - Finite Interaction Test

3.0. Human-Machine Integration Performance Metrics
- 3.1. Anthropometric Measures
  - Static
  - Dynamic

Table I. Listing of Current HFE Technologies (Continued)

- 3.2. Physiological Measures
  - FFF (Flicker Fusion Frequency)
  - GSR (Galvanic Skin Response)
  - EKG (Electrocardiogram)
  - EEG (Electroencephalogram)
  - ECP (Evoked Cortical Potential)
  - Eye and Eyelid Movement
  - Pupillary Dilation
  - Muscle Tension
  - Heart Rate
  - Breathing Analysis
- 3.3. Human-Machine-Environment Measurement Techniques
  - Noise Map/Fill
  - Vibration
  - Impact
  - Acceleration
  - Noise Mapping
- 3.4. Subjective Opinions
  - Questionnaires/Checklists/Ratings
    - Open-Ended
    - Multiple Choice
    - Rating Scales
    - Ranking Procedures
    - Forced Choice
    - Semantic Differential
    - Critical Incidents
- 3.5. Automatic Recording Methods
  - Event Recording
  - Photography
  - Audio/Video Tapes
  - Motion Pictures
  - OPRENDS (Operational Performance Recording and Evaluation Data System)
  - Recorded Flight Data

4.0. Models

- 4.1. Biomechanical Models
  - Architectural Body Models
  - Dynamic Dan
  - Combiman
- 4.2. Performance Models
  - Information Theory
  - Statistical Decision Theory
    - TSD (Theory of Signal Detectability)
    - Bayesian Decision Making
  - Estimation theory

Table I. Listing of Current HFE Technologie (continued)

Control Theory
  Quasilinear Control
  FFM (Fixed-Form Models)
  OCM (Optimal Control Models)
Queueing Theory

4.3. Process Models
  Short-Term Memory Models
  Visual Scanning/Detection Models
    GRC (General Research Corporation)
    MARSAM II (Multiple Airborne Reconnaissance Sensor Assessment Model)
    VISTRAC (VISual Target Recognition and ACquisition)
    CRESS/SCREEN (Combined Reconnaissance, Surveillance, SIGINET/SRI Countersurveillance Reconnaissance Effectiveness Evaluation)
    Autonetics Model
    Detect
    ASTCAD
    REA/BAC
  Air Traffic Control Models
  Industrial Inspection Models
  Attention/Workload Models
  Fault-Diagnosis Models
  HOS (Human Operator Simulation Model)

5.0. Engineering Design Simulation
  5.1. Human-Machine Integration Engineering Research Simulation
    General Purpose Static Aircraft Crew Station
    General Purpose Dynamic Aircraft Crew Station
    General Purpose Control Display
    General Purpose Multiperson
  5.2. Human-Machine Integration Engineering Design Simulation
    Static Mockup
    Specific Dynamic Control/Display
    Specific Crew Station
    Outside Dynamic Visual Scene
    Workplace Simulator
    Multiman Workstation
    Command and Control Simulation
    Sensor Simulation
    Computer Simulation

6.0. Procedures
  6.1. Systems Engineering Analytic & Management
    6.1.1. To Aid System Engineering Analysis
      6.1.1.1. Manual
        PERT (Program Evaluation and Review Techniques

Table 1. Listing of Current HFE Technologies (Continued)

- TLA-1 (Time Line Analysis-1)
- CMP (Critical Path Method)
- Expected Value Method
- Functional Flow Diagrams
- FDI (Functional Description Inventory)
- Function Allocation Tradeoffs
- Task Analysis
- Decision Tree Analysis
- Action/Information Requirements
- Time Lines
- Flow Process
- OSD (Operational Sequence Diagrams)
- Task Descriptions

6.1.1.2. Computerized

- SW (Siegel-Wolf Model)
- SAINT (Systems Analysis of Integrated Networks of Tasks)
- PSM (Pilot Simulation Model)
- CAPA (Computer Analysis of Personnel Activity)
- GERT (Graphical Evaluation and Review Technology)
- FOVEA (Field Of View Evaluation Apparatus)
- WSP (Workload Simulation Program)
- R&M (Reliability and Maintainability Model)
- Sensitivity Analysis

6.1.2. To Extract From a Design

6.1.2.1. Manual

- CHRT (Coordinated Human Resources Technology)
- HR/DODT (Human Resources/Design of Option Decision Trees)
- QQPRI (Qualitative and Quantitative Personnel Requirements Information)
- ISD (Instructional System Development)
- CDB (Consolidated Data Base)
- Comparability Analysis
- Technical Order Function Evaluation
- TEPPS (Technique for Establishing Personnel Performance Standards)

6.1.2.2. Computerized

- LCCIM (Life Cycle Cost Impact Model)
- TRAMOD (Training Requirements Analysis MODel)
- PAM (Personnel Availability Model)
- LCOM (Logistics Composite Model)

Table I. Listing of Current HFE Technologies (continued)

CORELAP (Computerized RElationship LAy-out Planning)

6.2. Detailed Design Procedures

6.2.1. Manual

Specification Compliance Summary Sheet
Link Analysis

6.2.2. Computerized

HECAD (Human Engineering Computer-Aided Design)
CATTS (Continuous Assessment of Task Time Stress)
TBLA (Time-Based Load Analysis
RECEP (RElative Capacity Estimating Process)
CAFES (Computer Aided Function Allocation and Evaluation System)
DMS (Data Management System)
FAM (Function Allocation Model)
WAM (Workload Assessment Model)
CAD (Computer-Aided Crew Station Design Model)
CGS (Crew Station Geometry Evaluation Model)

The task study first conducted a workshop in January 1979 with twenty-six key human factors engineers from government and industry to identify technological gaps and problems. From this initial workshop, a comprehensive questionnaire was developed based on the technology categories identified in Table I, to further determine the relative degree of use of these technologies in the Laboratory and Systems development environments.

This questionnaire, based on the technology areas in Table I, was used to assess the degree of utilization of the respective technologies throughout the research, development, test and evaluation phases of the system acquisition process. The questionnaire was distributed to more than twenty (20) industrial organizations with known human factors experience. Responses covered thirty-nine (39) specific weapon and subsystem development programs including fighter and bomber aircraft as well as certain command and control systems covering a ten year period from the late sixties to the late seventies. A comparable questionnaire was administered to over one hundred (100) government human factor engineers in Air Force Laboratories or engineering development organizations.

Table II summarizes the findings of percentage use of the six technology categories tabled across industry managers and project engineers vs. government applications and laboratory responses. It is evident from these percentages that reference data sources receive a high utilization rate across the board whereas models have a low utilization rate by all respondent categories. This finding probably

Table II. Average Percent Use of General HFE Technology Categories

General HFE Technology	INDUSTRY 1. Managers (15)	INDUSTRY 2. Projects (39)	GOVERNMENT 3. Applications (71)	GOVERNMENT 4. Laboratories (41)
Reference Data Source	67%	55%	46%	42%
Experimental	52%	29%	22%	51%
Human Performance Metrics	47%	30%	28%	33%
Models	13%	10%	6%	17%
Engineering Design Simulation	68%	50%	34%	39%
Procedures	26%	21%	16%	14%

reflects on the technological lag encountered in more sophisticated and quantitative mathematical modeling methods.

Table III breaks down the broad category response into selected detailed HFE technology areas by industry and government respondents. These data further illustrate that for all respondent categories that the more established technologies (Reference Data Sources, Statistical Research Methods, Anthropometric Measures and Design Simulation Methods) are the most frequently used. The newer technologies involving mathematical modeling and computerized techniques are not utilized much. This fact underscores the technological lag problem. At the bottom of the table the intercorrelations between respondent categories, demonstrate the lack of relationships between laboratory scientists' utilization of these technologies and the applications human factors engineers ($Y_{1,4} = .85$, $r_{2,4} = .72$, $r_{3,4} = .76$). Whereas the correlation between technology use between managers, project personnel and government applications personnel are somewhat higher. One possible interpretation of these findings is that the technology transfer between the technology developers (laboratory scientists) and the human factors engineers (both management and project) remains a problem of some significance.

This technology transfer problem may stem from several sources, but two facets merit special concern. First, at least in the USAF Research and Development Community, there is no well defined management mechanism to insure efficient feed-forward from the laboratories to the developers nor is there a feed-back formalized procedure from the operational environment to the laboratory and development programs. Secondly, most laboratory research is conducted with basic research (6.1) or exploratory development (6.2) funding and very few programs see the "prototype" development stage (6.3). Hence, the meth-

Table III. Average Percent Use of Detailed HFE Technology Category

Detailed HFE Technology Category		INDUSTRY 1. Managers (15)	INDUSTRY 2. Projects (39)	GOVERNMENT 3. Applications (71)	GOVERNMENT 4. Laboratories (41)
1.0.	Reference Data Sources	67%	55%	46%	42%
2.1.	Statistical Research Methods	79%	42%	34%	77%
3.1.	Anthropometric Measures	18%	12%	7%	19%
3.2.	Physiological Measures	80%	78%	47%	32%
3.3.	Environmental Measures	44%	26%	38%	21%
3.4.	Subjective Opinions	58%	45%	37%	49%
3.5.	Automatic Recording Measures	71%	47%	41%	58%
4.1.	Bioman Models	13%	10%	2%	4%
4.2.	Performance Models	17%	13%	11%	28%
4.3.	Process Models	11%	8%	4%	12%
5.1.	Engineering Research Simulation	68%	43%	26%	28%
5.2.	Engineering Design Simulation	68%	53%	37%	44%
6.1.1.1.	Manual Systems Engineering Analysis	65%	53%	36%	37%
6.1.1.2.	Computerized Systems Engineering Analysis	7%	6%	6%	6%
6.1.2.1.	Manual Procedures from Design	9%	10%	15%	7%
6.1.2.2.	Computerized Procedures from Design	5%	4%	6%	2%
6.2.1.	Manual Detailed Design Aids	40%	33%	19%	16%
6.2.2.	Computerized Detailed Design Aids	8%	4%	3%	1%

Correlations

$r_{1,2} = .95$ $r_{1,4} = .85$

$r_{1,3} = .92$ $r_{2,4} = .72$

$r_{2,3} = .93$ $r_{3,4} = .76$

odological tools involving computer-based modeling and simulation have no formal R&D management structure to demonstrate verification, validation and utility for developmental design application.

Based on the analysis and evaluation of the questionnaire results on current HFE technology several observations and conclusions can be drawn. First, although the reference data sources are used in weapon system development more than the advanced technologies of models and computerized procedures, it appears that the requirement exists for improving the package of the reference data sources in terms of handbooks, guides and the like so they are more amenable to design use. In fact, the development of a computerized reference data bank may be in order which would allow HFE data to be responsive to specific design issues. A better designed reference system which could feed the computer modeling and computer-based proceduralized systems appears to be in order. A renewed effort should be launched to transfer the computer-based technology into the implementing hands of the applied human factors engineers with more enphasis on validation of these methods throughout the development and test phases. The need exists for integration of computer-modeling and engineering design simulation to developed hybrid techniques to exploit the respective powers of both in a cost-effective manner.

FUTURE REQUIREMENTS

To anticipate the directions of new methods and predict future projections of needed technology, the Air Force HFE study will again be used as a data base along with another study sponsored by the Air Force Systems Command designed to define computer technology shortfalls to the year 2000 (COMTEC-2000) (Computer Technology Forecast and Weapon Systems Impact Study, 1978). Only the man-machine interface technology part of this comprehensive study will be referred to in developing future requirements.

Future Technology Assessment Study

To assess future technology projections twenty nine (29) experts from industry, government and academics were asked to write technology projections, both near-term (3-5 years) and far term (5-15 years) in seventeen (17) technology areas listed in Table IV. (Some areas were covered by one or more experts.) The 17 technology areas were collapsed into nine (9) human factors information needs identified in Table V and analyzed across three (3) levels - human centered, human-machine centered or human-machine-mission focused. Most experts (54%) indicated a preponderance of future technology needs in the area of man-machine-mission as compared to human (12%) or human-machine (34%) applications. They also indicated information need for system operation (20%) and design principles/concepts (29%) with design data base/handbook (15%) being the third highest

Table IV. Representative areas of future HFE technology projections

* Advanced display engineering technology
* Human factors in maintainability
* Systems research technology
* Human factors in safety engineering
* Engineering anthropometry
* Human/computer interactions
* High thermal stress
* Training analysis and simulation
* Biocybernetics
* Operator/crew workload
* Computer modeling and simulation
* Design guides and data bases
* Advanced cockpit technology
* Target detection/acquisition models
* Decision making
* Human factors in manufacturing technology
* Manpower and logistics factors in weapon system development

Table V. Summary of future HFE technology projections

		12%	34%	54%	
HFE Information Needs	Systems Operation	3%	6%	11%	20%
	T&E Procedures	-	1%	5%	6%
	Training Development	-	3%	4%	7%
	Training Requirements	1%	4%	4%	9%
	Personnel Selection	-	1%	1%	2%
	Personnel Requirements	1%	2%	2%	5%
	Design Principles/Concepts	4%	10%	15%	29%
	Design Database/Handbook	3%	5%	7%	15%
	MENS	-	2%	5%	7%
	HFE LEVELS OF ANALYSIS	H HUMAN	H/M MACHINE	H/M/M MISSION	

information need category. It is fairly obvious that most of the advanced thinkers in the human factors discipline believe that the greatest needs for future technology development are being driven by the requirement for a human-machine-mission (H-M-M) systems analytic and

simulation capability. This human factors system capability is in turn being driven by high technology advanced in hardware/software computer developments creating monumental complex information processing requirements combined with mission threats becoming more challenging and evasive. H-M-M systems analysis and simulation methods must be developed to treat human, equipment and mission parameters in equivalent quantitative terms in order to isolate this respective contribution to overall systems effectiveness.

Williges and Topmiller (in press) conclude from the technology assessment that - Advances in other life sciences, engineering, and computer science along with consideration of energy supplies, future threat environments, and future weapon systems appear to provide the major impetus for future threat environments, and future weapon systems appear to provide the major impetus for future HFE technology developments. Current DOD research plans and activities reveal that these influences are driving the developments of models, computer simulation, display assessment, multi-operator systems, advanced cockpit considerations, management technology and biocybernetics. Future research is needed in maintenance design and analysis, engineering anthropology, safety system research, human/computer interfaces, and human/machine environments. Both near-term and long-term advances are required in each of these areas in order to provide the appropriate technology base for HFE.

Williges and Topmiller make the following recommendation regarding the implementation of computer-based HFE technology: Various computer-based procedures for HFE are currently available and near-term projections suggest even more improvements and developments in these procedures. But, by and large, this technology is not being implemented heavily in the design process. Several reasons, such as the unavailability of the procedures, the lack of knowledge of the procedures, and nonexistence of contract requirements to use them have been given for their sparse use. Before these various techniques can be completely evaluated, they must be integrated.

Little effort, however, has been directed toward integrating all of these approaches into a truly, computer-based HFE design methodology and providing a testbed for application and further development. Such an integrated methodology would include using computer-analytic models and engineering design simulation could be effectively used in interactive manner throughout conceptual design, fly-offs between design configurations could be accomplished by large-scale, total mission simulation, computer modeling could suggest alternative configurations for simulator evaluation, and engineering design simulation could be used as a means of specifying training requirements and follow-on trainer design.

The Human Factors Engineering Technology Assessment Study was conducted by, and participated in, by practicing HFE scientists, prac-

titioners and managers. The survey and review results certainly yield one common theme, viz. that computer technology has driven much of the advanced HFE technology developmental needs. It was somewhat fortuitous that about the same time the Air Force was making a self-appraisal of HFE, it was also launching a major study effort to predict future thrusts of computer technology development and the impact these developments will have on future weapon system design concepts. The approach used was to identify and classify the areas upon which logical estimates of risk/benefits could be made to assess future investment strategies and to also identify existing R&D programs which would serve as technology drivers for the identified areas. This study is significant since it was created and conducted under the general direction of the computer science community and not the NFE community, although the study directors recognized that the man-machine-interface technology plays a significant role in making the predictions consistent with three primary objectives

1. Forcast the advancement of computer and computer-related telecommunication technologies.
2. Assess the potential impact of these technology advances on the capabilities of existing or future weapon systems through the year 2000.
3. Determine the policies and R&D initiative required to bring these technology advances to fruition and to incorporate them in future weapon systems capabilities.

This study was known as COMTEC-2000 for Computer Technology Forecast and Weapon System Impact Study for the next 20 years.

COMTEC-2000 MAN-MACHINE INTERFACE TECHNOLOGY SHORTFALLS

A special panel was formed as part of the overall study effort to identify and project man-machine interface technology shortfalls. The panel was chaired by Donald L. Monk from our Laboratory, with members representing Flight Dynamics Laboratory, Human Resources Laboratory and the Mitre Corporation. Fig. 1 shows the human computer technology shortfalls roadmap which the panel developed to define the drivers of the technology needs which in turn determine the four (4) man-computer interface areas of: Information Exchange, Human-Computer Symbiosis, Standards and Guidelines, and Design and Evaluation Methodologies. These technology area mechanisms were evaluated in terms of state-of-the-art to yield the final products for better and more effective computer interfaces designed for man.

Fig. 2 shows the risk/payoff matrix for five (5) subareas of information exchange and Fig. 3 expands these five areas in a roadmap which shows how current man-machine interface research in head/eye tracking, neurophysiological/measurement (EEG), pilot workload assessment, multi-function keyboard design, and voice control techniques

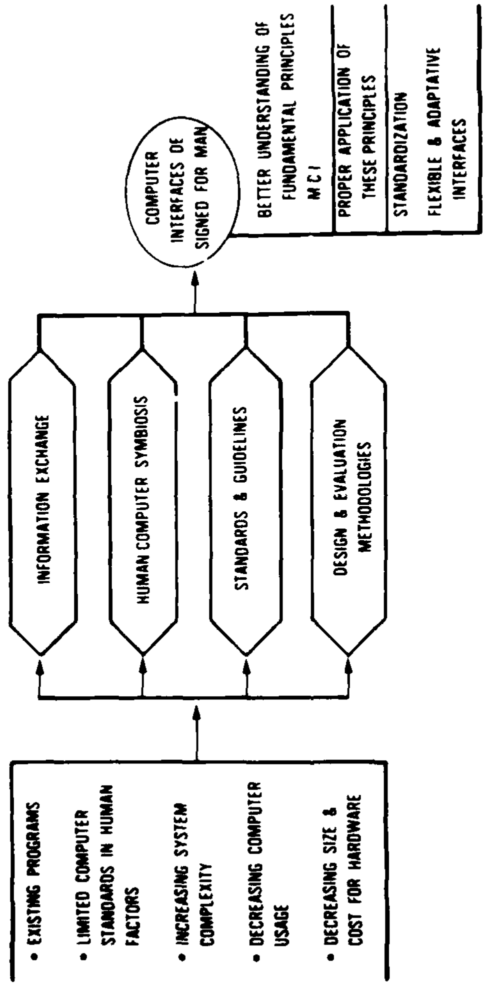

Fig. 1. Human-computer technology shortfalls roadmap

AREA	RISK	PAYOFF	COST	NEED
GRAPHIC TECHNIQUES	L	M	M	M
MULTIFUNCTIONAL INTEGRATED SYSTEMS	L	H	M	H
SELECTION/CONTROL DEVICES	L-M	M	L-M	M
NATURAL LANGUAGES	M-H	H	M	M
IDEOGRAPHS	L	M	L	L-M

Fig. 2. Information exchange

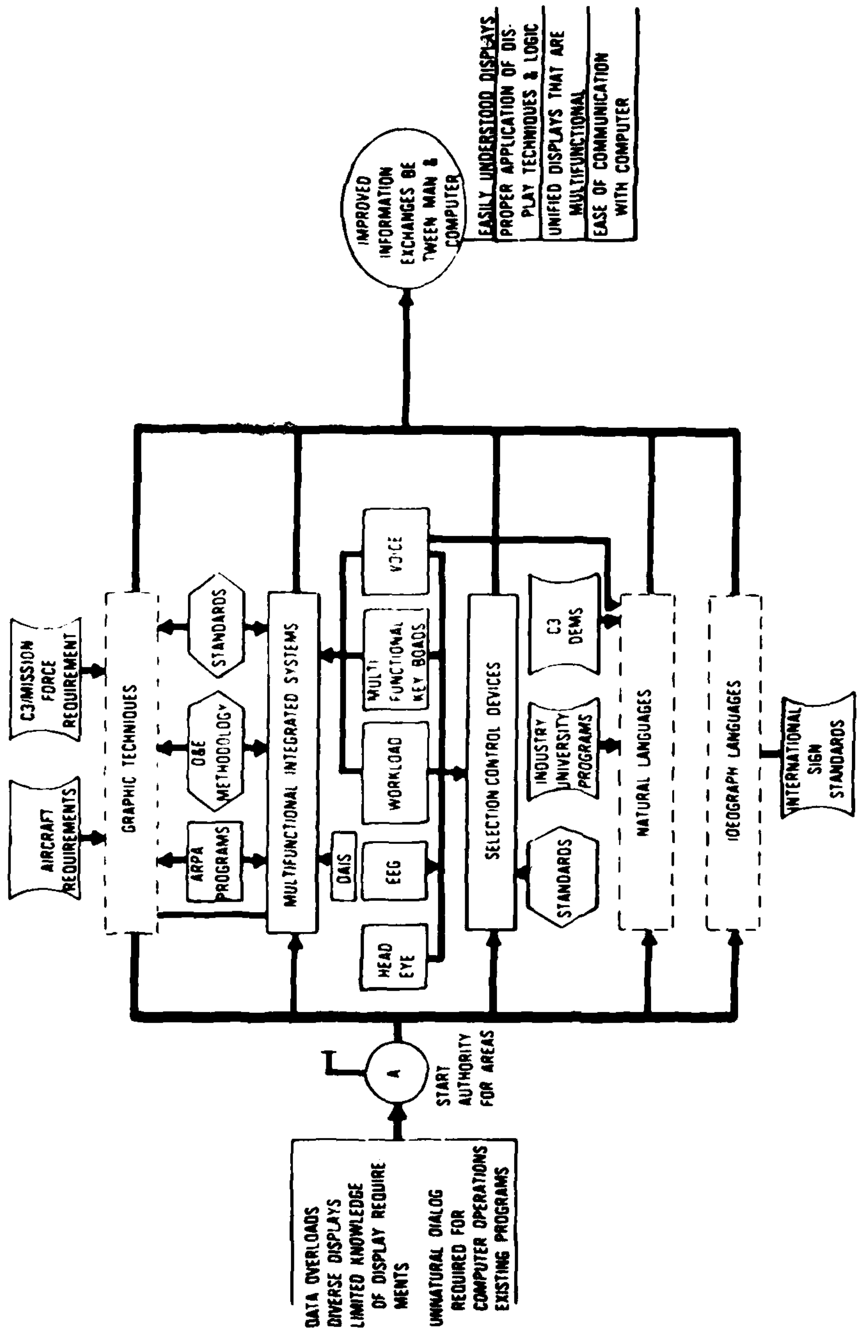

Fig. 3. Information exchange roadmap

serve as the technology base to feed the five (5) areas of improved human-computer interface information exchange. From Fig. 2 the areas needing higher priority on the basis of low to medium risk and cost vs medium to high payoff are improved graphic techniques and more operator oriented multi-functional integrated systems. Computer graphic techniques are becoming extremely powerful and present the potential for manipulating and controlling perceptual cue to enhance the effects of size, distance and motion constancies for specific display renditions. Multi-function systems (displays and controls) must be designed for compatability with certain human cognitive capabilities and limitations including short-term memory.

Figs. 4 and 5 show the risk-payoff matrix and associated roadmap respectively for the area of human-computer symbiosis. It would appear that the potential for developing imbedding training techniques with interactive systems has not been fully exploited by the human factors and computer science communities. Principles for automatic self correcting and operator prompting techniques should be developed exploiting current knowledge of adaptive aiding techniques and artificial intelligence algorithms. Adaptive techniques could be used to automatically sense high operator workload periods to temporarily store information cues to pace and synchronize with operator capacity/demand information.

One of the major thrusts in new weapon system developments is in the command, control and communications (C^3) area. The requirement for voice control techniques for C^3 systems is an advanced HFE technological need which emphasizes the burgeoning developments in "human centered" design.

A requirement also exists for a "Trainable Command and Control Information Processing System". In a modern tactical threat environment, it is not simply the collection and display of information that must be automated, but, of equal importance, the utilization of that data. A target nomination should be able to trigger a sequence of semi-autonomous processes sufficient to suggest a mission profile for the approval of a responsible duty officer. It is necessary that the future tactical command and control systems be modified on-line in response to unforeseeable demands of the battle situation.

Since C^3 data base systems are becoming to gargantuan, it is necessary to develop "knowledge-based fusion systems" where fusion is not only the merging of multi-sensor data, but the interpretation of these data achieved by their integration with other data and knowledge of a symbolic nature. The need for new ways to display and integrate these fusion systems present a challenging HFE problem.

Even given the current embryonic state of human-computer interface design it would appear urgent to initiate national and international programs to develop standards and guidelines for symbology,

AREA	RISK	PAYOFF	COST	NEED
FUNCTIONAL ALLOCATION	M	H	M-H	M
EMBEDDED TRAINING	L-M	M-H	M	M
HUMAN INTERACTION WITH AI	M-H	H	M-H	L

Fig. 4. Human-computer symbiosis.

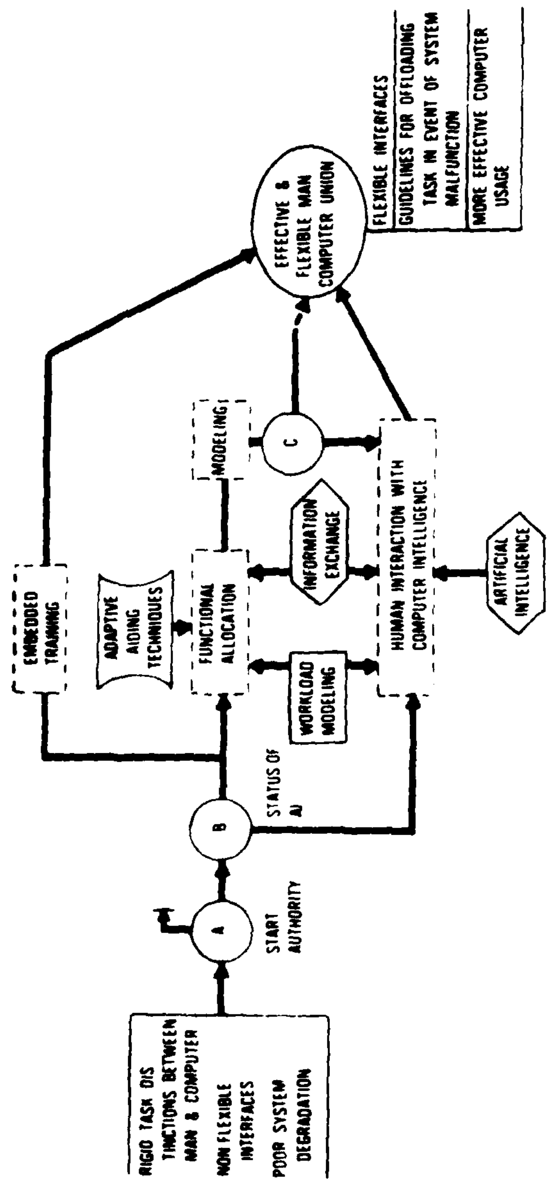

Fig. 5. Man-computer symbiosis roadmap.

display formats, command languages and equipment with Human Factors Engineers and Ergonomists playing a central role in their development. Figs. 6 and 7 again outline the risk/payoff analysis and the roadmap for developing these standards and guidelines. Certain triservice (Army, Navy and Air Force) programs including the Joint Tactical Information Display System (JTIDS), Digital Avionics Information System (DAIS) and various Command/Control programs designed for interoperability could presently use preliminary standards and guidelines in these areas. Eventually, the DOD developed standards will require international coordination and agreement for NATO joint force implementation. It is probably not too early to establish NATO committees to initiate preliminary development of international standards in the areas.

Finally, programs should be established to develop design and evaluate methodologies. A listing of eight (8) subareas to be addressed in such programs are included in Fig. 8 with the proposed roadmap for integrating these efforts in Fig. 9. Function and task taxonomies are needed along with integrated modeling approaches to quantitatively specify human-computer interface requirements to anticipate new conceptual design requirements for advanced computer-based systems with the ultimate goal of predicting overall systems performance and effectiveness well in advance of committing to a particular design configuration.

The COMTECH-2000 Summary Report concludes with the following statement: Man-machine interface will improve in response to the commercial market competition for sales to the layman of increasingly sophisticated devices. The trend will be for devices to be self-describing, assisting, the uses in their operation and maintenance. A continuing important, relatively unchanging role for men in the Air Force is forecast; and the national manpower pool from which they will be drawn will increasingly have computer experiences - it is estimated that by 1985 some 75 percent of the nations' work force will be working with computers. Man-machine dialogue will improve as better models of the data base, the uses, and his objectives are incorporated into the computer. Modalities of dialogue will range from keyboard, light-pen, and touch, through tablet and voice, to eye-movement and electroencephalogram. The latter three are of potentially great interest to the Air Force and may not fully develop from commercial R&D alone. A more intelligent, situations-dependent use will be made of display space. Similarily, programmable manipulands (e.g. soft-copy keyboards) will be developed by the commercial sector. Finally, there is a tantalizing prospect of computer mediated translations (in a limited context) from language to language and/or from verbal to pictorial representaions (ideographs).

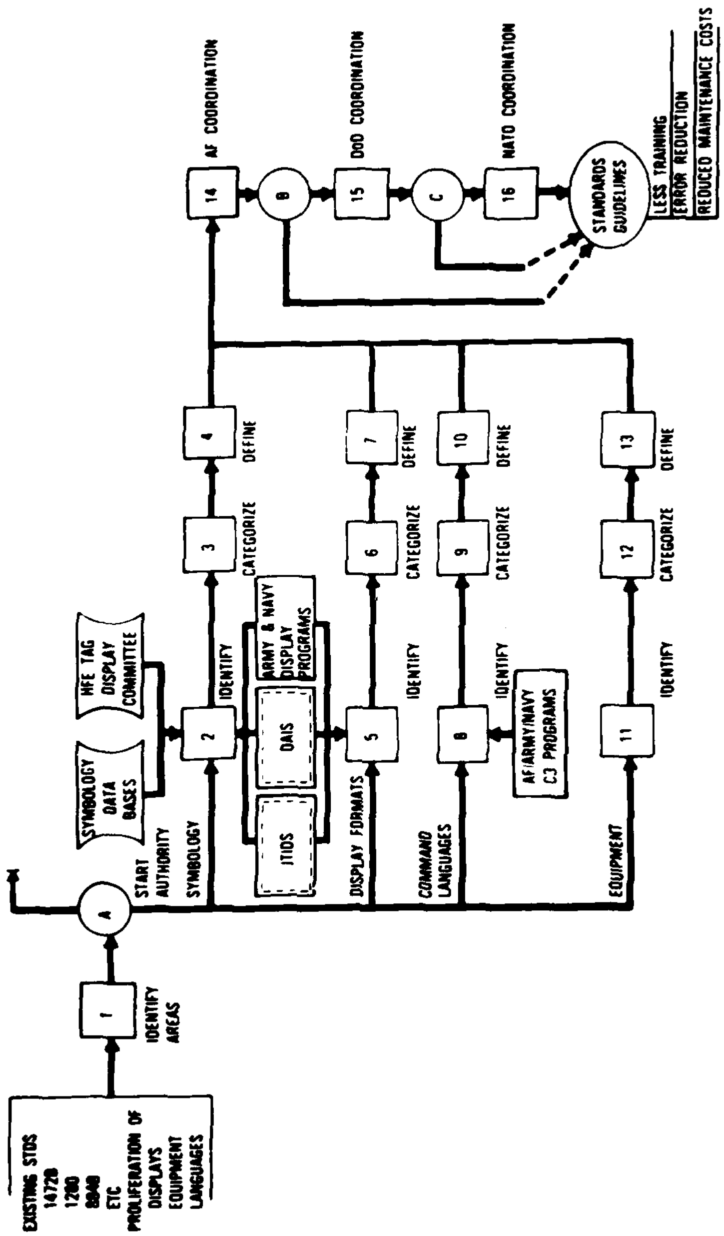

Fig. 6. Standards and guidelines roadmap.

AREA	RISK	PAYOFF	COST	NEED
SYMBOLOGY	M	H	L-M	H
DISPLAY FORMAT	M	M	L-M	M-H
EQUIPMENT	L	M	L	M
COMMAND LANGUAGES	M	H	L-M	H

Fig. 7. Standards and guidelines.

AREA	RISK	PAYOFF	COST	NEED
FUNCTION TAXONOMY	L	M-H	L	M-H
PROBLEM/APPLICATION TAXONOMY	L	M-H	M	M-H
GENERIC TASK TAXONOMY	M-H	H	M-H	H
GENERIC MODELS	M-H	H	M-H	H
GENERIC H.O. MODELING	M	M-H	M	M-H
HUMAN FACTORS METRICS	M	M-H	M-H	M-H
DESIGN GUIDE	M	H	M	H
SIMULATION/MODELING TESTBEDS	M	H	H	H

Fig. 8. Design and evaluation methodologies.

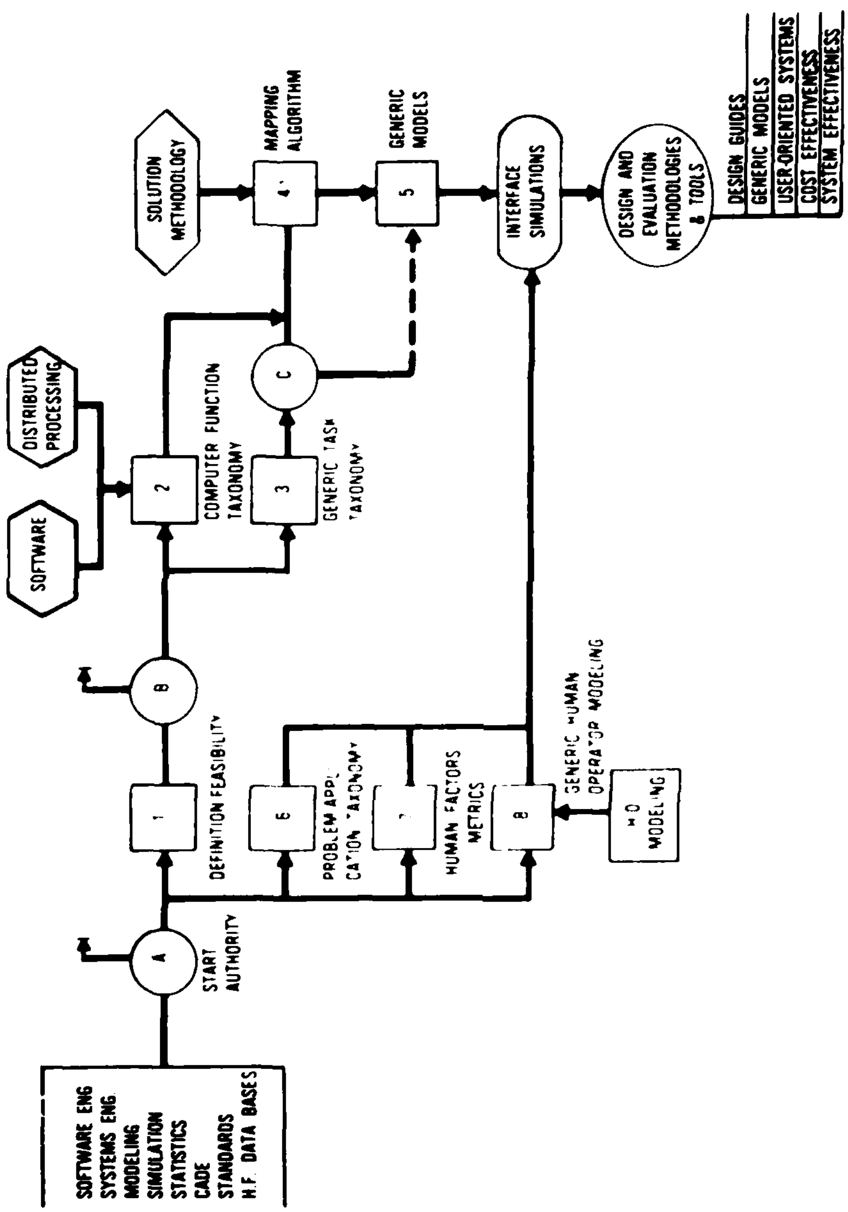

Fig. 9. Design and evaluation methodology roadmap.

SUMMARY AND CONCLUSIONS

This paper has attempted to review some of the historical development, current state-of-the technology and practices as well as estimates of future technology directions and trends in methods, techniques and data bases for man-machine interface design and their interrelationships with system design considerations.

Past, and to some extent current methods have, and are, using primarily the established data bases and manual analytic and design tools. The more advanced technologies which employ computer-based analysis and simulation await full application to the design process pending acceptance and technical upgrade of the practicing human factors engineers working in the system development and acquisition process. It is anticipated that within the next five (5) to ten (10) years we will see an upsurge in the exploitation and use of computer-based simulations and modeling, a rapid assimulation of engineering design simulation employing man-in-the-loop evaluations of advanced man-machine interface concepts including voice control and the use of adaptive neurophysiological control techniques to generate display information requirements as a function of mission demand. We should also see an increased emphasis on man-machine design considerations in overall "cost-of-ownership" and "life-cycle-costing" estimations earlier in the design and development sequence. Overall mission simulation capability will be an increasing requirement for system development programs. It is also anticipated that greater use will be made of "hybrid" simulation methods where the combined powers of computer-simulation and man-in-the-loop physical simulation will be used to anticipate the increasing complexities of operational tasks which are being driven by more sophisticated threats and equipment.

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